GPS Based Attitude Determination and Verification using a Serial Robotic Arm

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Abstract

In this work we propose an algorithm for determining the attitude of a rigid body in a three dimensional space. To do this, we use three L1 GPS sensors that receive signals from GNSS satellites. To test and verify our model we use a serial robotic manipulator, by changing the orientation of the manipulator's end effecter at predetermined rates with the rigid body attached along with the GPS sensors we can verify our mathematical model. The data obtained shows that our model works very well. In this paper we discuss both the mathematical model as well as the experimental setup for model testing and verification, and present our results.

Introduction

GPS based double-differenced carrier phase observables can be used for high precision attitude determination of the object, and the key is utilization of integer ambiguity resolution. Many methods are proposed and more recent ones make use of the LAMBDA which stands for Least-squares ambiguity Decorrelation Adjustment method.

In this article, we emphasize the real-time requirement of attitude determination of the moving object and propose a reliable single frequency, epoch by epoch attitude determination method constrained by baseline lengths and an auxiliary dynamic model of the platform. This method utilizes prior information of baseline lengths and the predictive model of the rotating platform based on its potential trajectory and angular rates of rotation. Then, we give an overview of the corresponding software designed to implement the mathematical model above. Finally, we report the static and dynamic tests to provide sufficient results that indicate good performance of the proposed mathematical algorithm.

Mathematical Model

GPS models have two main types; non-positioning or geometry-free models and the positioning or geometry-based models. Furthermore, various GPS models might be distinguished by virtue of the differencing which is utilized. By differencing, we mean to take the differences between measurements from different receivers and/or different satellites
In general, all GPS baseline models can be put in the following formula of linearized observation equations according to a Gauss-Markov model.

$$E(y) = Aa + Bb;\ D(y) = Qyy$$

Where y is the known GPS data vector of order m, a and b are the unknown parameter vectors of order n and p respectively. $E(:)$ and $D(:)$ denote the expectation and dispersion operators, and A and B are the given design matrices which bound the data vector to the unknown parameters.

System Design

We developed the algorithm for attitude determination by measuring of phase difference of the GPS carrier signal observed at three antennas. It is known that carrier phase GPS readings are subject to the issue of undesirable cycle slips. Once there is a cycle slip in one receiver due to low signal to noise ratio or loss of track of the Doppler filter, the error will propagate and obscure an accuracy of the angular solution. So the double difference measurements are used to furnish this GPS-based attitude determination approach. In order to determine the attitude from GPS carrier phase measurements, we have to resolve ambiguities. In other words, we have to find the correct carrier phase integer ambiguity values. This is the key to GPS attitude determination.

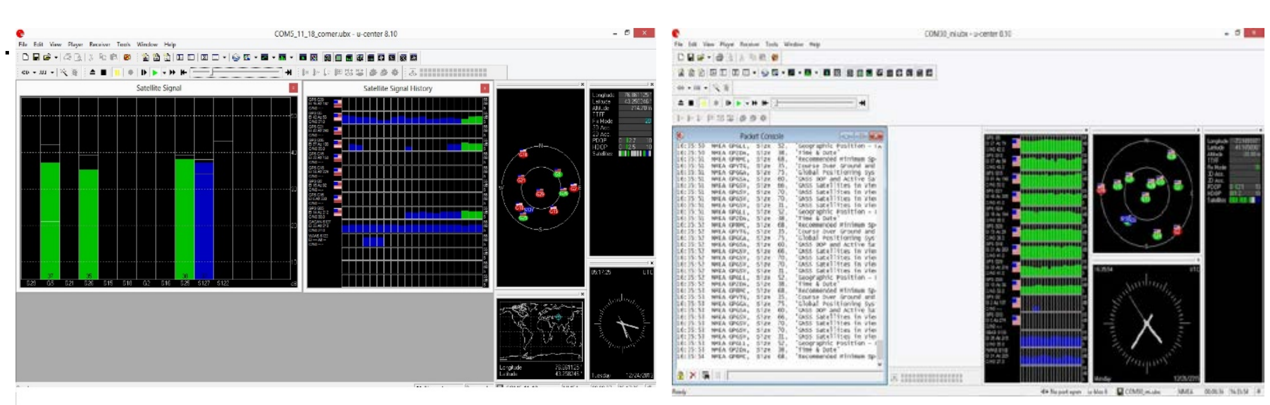

Figure 1: Displaying the position of an object by means of U-blox GPS signals

Experimental Setup

In order to test performance of the developed algorithm, a set of experiments were conducted in this study. Three GPS sensors U-blox AEK-4T single-frequency low-cost receivers, 0.045 deg (RMS) for heading angle, average baseline of 3 meters and using the computational techniques such as carrier phase double difference technique; integer ambiguity search through applying Kalman filter algorithm and figure 1 shows the GPS signals received by the GPS sensors from various overhead satellites and the GPS coordinates the sensor. Figure 2a shows the triangular setup of GPS sensors separated mutually by 1 meter each and figure 2b shows the setup with the Mitsubishi Movemaster serial manipulator with GPS sensors held by the serial arm.

The manipulator's end effecter is programmed to change its orientation at a predetermined rate. Just before starting of these three dynamic tests, corresponding experiments in static modes were carried out to provide the initial attitude angles which were used in the verification analysis afterwards.

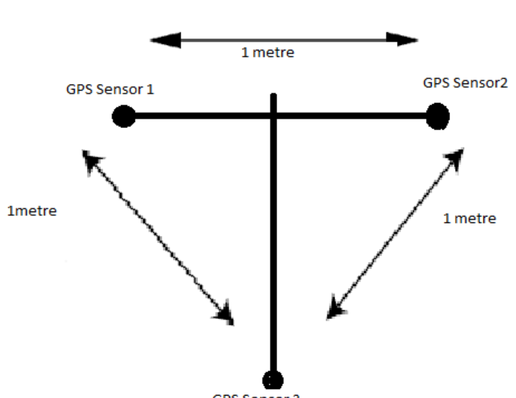

Figure 2a

Figure 2b

The basic experimental setup and setup with serial robotic arm

Experimentation and Results

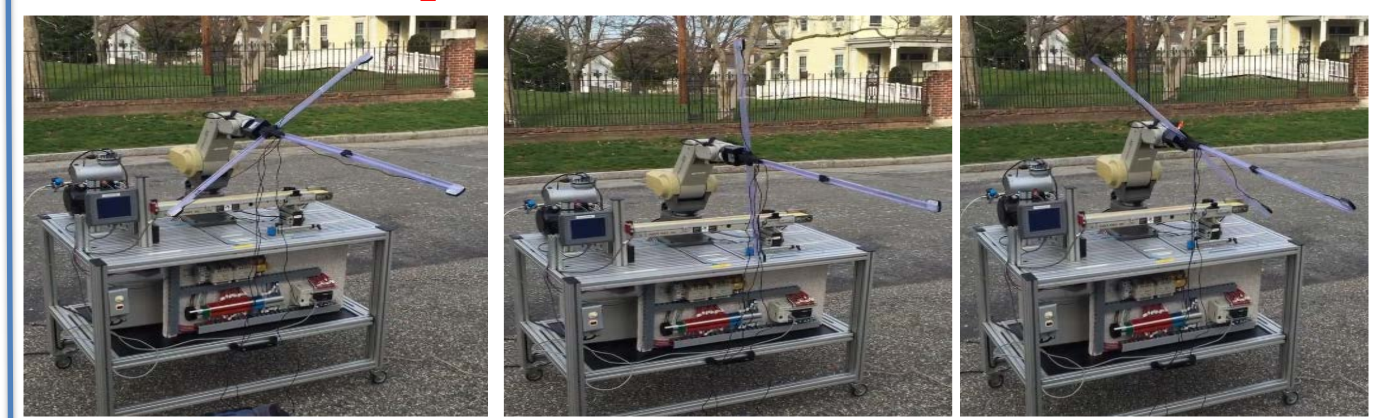

Figure 3: Experimental testing of Roll angle motion of an object

Figure 4: Experimental testing of Pitch angle motion of an object

Figure 5: Experimental testing of Yaw angle motion of an object

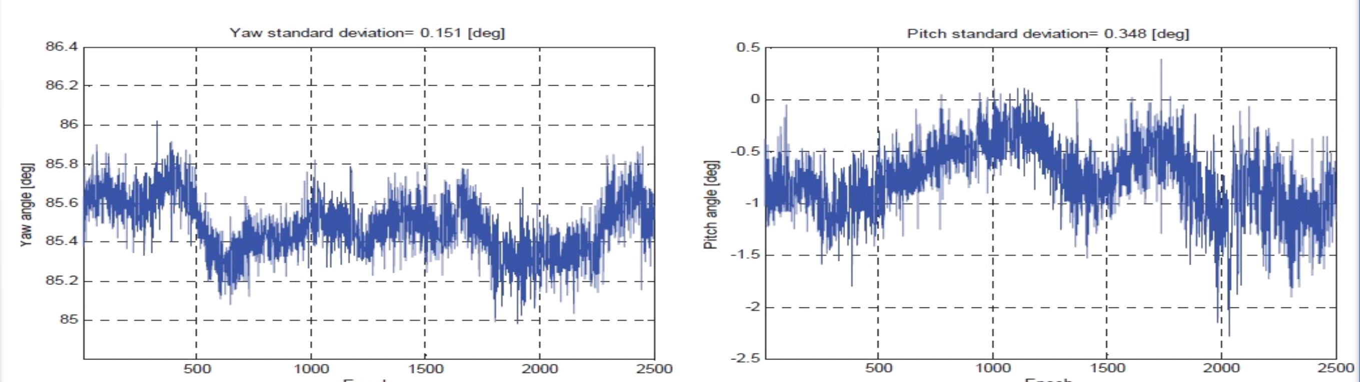

Figure 6 : Computation of yaw and pitch angles in static mode

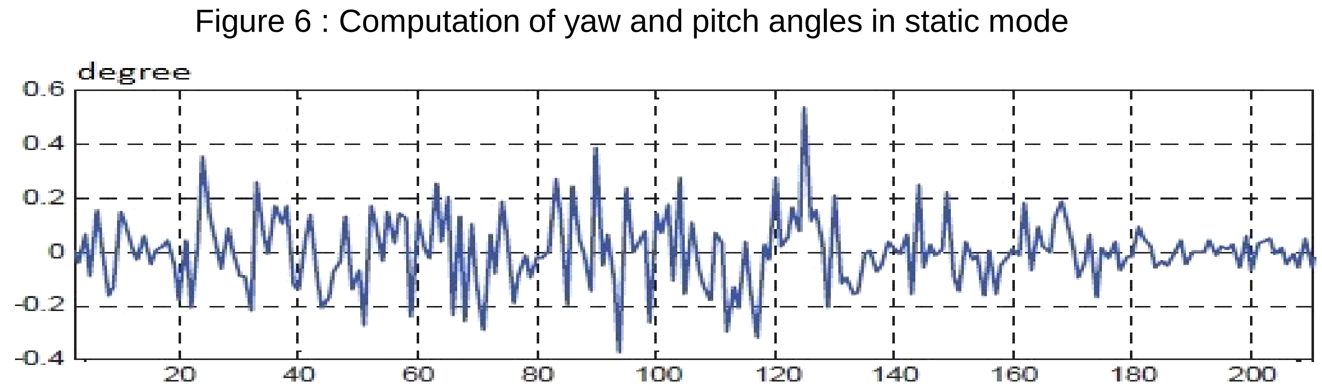

Figure 7 : Verification of yaw angle determination in dynamic mode

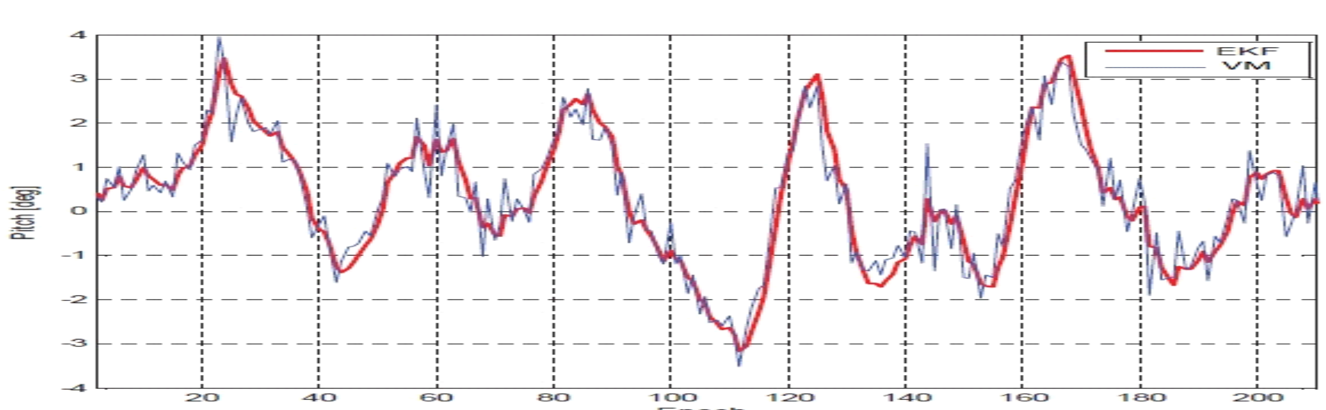

Figure 8 : Verification of pitch angle determination in dynamic mode

These data interruptions took place because of carrier phase cycle clips caused by the particular rotation plane of the platform that partially prevented a line of sight with navigational satellites. The above figures 3,4 and 5 demonstrate the experimentation for roll, pitch, and yaw angle motions.

Conclusion

Our goal was to develop GPS-based attitude determination algorithm based on the predefined dynamic model. The performance of this technique was tested in a series of experiments by using a serial robotic arm. Finally, accuracy of this algorithm can be improved by incorporating appropriate cycle slip repair method for post processing of the occurred data gaps.

Videos

Please scan the following QR codes to view the videos of Roll, Pitch, Yaw testing

Roll Pitch Yaw